PB90-132416

Defining Regions for Evaluating Environmental Resources

(U.S.) Corvallis Environmental Research Lab., OR

1989

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1. REPORT NO.	2.	3. Ri PB90-132416
EPA/600/D-89/265		

4. TITLE AND SUBTITLE	5. REPORT DATE
Defining Regions for Evaluating Environmental Resources	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S)	8. PERFORMING ORGANIZATION REPORT NO.
James M. Omernik and Alisa L. Gallant	
9. PERFORMING ORGANIZATION NAME AND ADDRESS	10. PROGRAM ELEMENT NO.
US EPA, Corvallis; NSI Tech. Serv., Corp., ERL-Corvallis	11. CONTRACT/GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS	13. TYPE OF REPORT AND PERIOD COVERED
US Environmental Protection Agency Environmental Research Laboratory 200 SW 35th Street Corvallis, OR 97333	Conference Proceedings 14. SPONSORING AGENCY CODE EPA/600/2

15. SUPPLEMENTARY NOTES
"International Conference on Global Natural Resource Monitoring and Assessment" Sept 24-29, 1989, Venice, Italy

16. ABSTRACT

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17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS (This Report)	21. NO. OF PAGES
Release to Public	Unclassified	18
	20. SECURITY CLASS (This page) Unclassified	22. PRICE A03

EPA Form 2220-1 (9-73)

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EPA/600/D-89/265

DEFINING REGIONS FOR EVALUATING ENVIRONMENTAL RESOURCES

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ABSTRACT

The need for regional frameworks for making assessments of environmental resources has been recognized for many years. However, attempts to define effective frameworks have met with only limited success. In the absence of a suitable available scheme, the U.S. Environmental Protection Agency developed, tested, and applied approaches for defining regional frameworks to meet both multi- and single-purpose needs. Ecoregions were mapped to facilitate the assessment of existing patterns and trends in the extent and quality of environmental resources (particularly aquatic) and relationships with natural and human-related factors. Definition of these regions was based on patterns of combinations of characteristics including land use, land surface form, potential natural vegetation, and soils. Other hierarchical levels of these ecoregions, including subregions and aggregations of ecoregions, are currently being developed for assessing agricultural, forest, wetland, and surface water ecosystems. Approaches have also been developed for defining regions for inventory, management, and monitoring of specific problems or environmental characteristics, such as acidification of surface waters and lake eutrophication. The definition of these regions is based on patterns of specific parameters, such as surface water alkalinity or total phosphorus in lakes, and apparent spatial associations between these patterns and landscape characteristics including surficial and bedrock geology, existing and potential vegetation, land use, and physiography. Although these approaches have been developed for national and regional scale uses, they afford a means for developing effective spatial frameworks for assessing environmental resources on a global scale.

THE NEED FOR REGIONS

People responsible for monitoring and assessing environmental resources have long recognized the need for regions and regional frameworks. Most have understood that the quality and quantity of environmental resources, the factors associated with between- and within-region differences, and the problems and issues facing humans vary infinitely from one part of the world to another. Fortunately, they have also realized that, albeit complex, these characteristics and concerns occur in spatial patterns. There are regions within which there is relative homogeneity in types of issues and problems, resource quantity and quality, and factors that affect differences in quality. These regions

exist and can be defined at all scales, from the broadest global scales to very detailed local scales. Accurate assessments of our global resources and the design of effective monitoring networks depend upon the proper use of meaningful regional frameworks. Extrapolation from existing data, as well as from data from monitoring stations, requires a thorough understanding of the regional representativeness of these data, which in turn depends upon the use and understanding of the most appropriate regional frameworks. Unfortunately, the task of defining regions has not met with a uniformly high degree of success. Although there are exceptions, many of these efforts have been fraught with inconsistencies, misdirection, and misunderstanding, often leading to ineffectual results. Much of the problem, however, lies in misuse of these regions rather than in their design. The information presented in this paper summarizes some of the problems with existing regionalization schemes and frameworks and briefly explains some of the approaches taken by the U.S. Environmental Protection Agency (EPA) to develop more effective frameworks for assessing environmental resources. A more detailed explanation of this material is contained in a recent publication entitled "Regionalization as a Tool for Managing Environmental Resources" (Gallant et al., 1989).

THE NATURE OF REGIONS AND BOUNDARIES

We believe that much of the difficulty scientists and managers have in addressing regional representativeness, and part of the failure of many regional frameworks to meet their intended goals, is due to a misunderstanding of the nature of regions and regional boundaries. Regions are thought by many to be what they are not--finite areas that can be defined precisely using specific rules. Probably the best explanation of regions and the dilemmas people have encountered in attempting to understand and define them has been given by John Fraser Hart (1982). Hart noted that although the concept of region is not a powerful technical tool, it is a useful intellectual device for organizing and presenting information. Hart stated:

> A region is simply a more or less homogeneous area that differs from other areas. To use more contemporary jargon, within-region variance is less than between-region variance. The "best" regions are those that are based on the greatest amount of interrelatedness.

The definition of any region or regional framework, the delineation of its boundaries, and the scale at which it is drawn (or "levels" if it is a hierarchical framework) is a function of the objectives or purpose of the framework. Regions drawn for general purposes, such as addressing patterns of ecosystems, must be drawn differently than those designed for specific purposes. For example, when tasked to provide military strategists with a spatial framework for examining broad-scale military operations scenarios for entire countries, military geographers define broad regions within which combinations of general conditions in such factors as climate, topography, soils, and vegetation are similar. Mapped information on a variety of geographic phenomena is necessary to determine these regions. For tasks of a more specific nature, say assessing regional patterns of suitability for assault air landings or for cover and concealment of troops, very specific sets of information would be needed and the resultant classifications and boundary alignments would have narrower applications.

The "moving target" nature of environmental phenomena must also be understood to evaluate the usefulness of regions and the confidence that can be put in the conditions they represent. Natural and anthropogenic characteristics that are being regionalized, as well as those that are used to define regions, are continually changing in very complex ways. Hence, regions that define similarity in environmental conditions must be considered as approximations. Precipitation maps, for example, define areas within which we can expect a particular amount of annual rainfall (and/or snowfall), based on an average of annual amounts for a specific period of years from a set of sampling stations. Extrapolations to areas without data are based on "expert judgement", which consists of an understanding of the effects of characteristics such as topography and weather patterns on regional differences in precipitation. Precipitation maps are extremely valuable for illustrating general patterns, but should not be used to make precise predictions. Similarly, exact quantitative determinations cannot be made of other environmental parameters, such as extent of area in lakes, numbers of lakes, stream locations, vegetation, and soil patterns, much less the quality of these phenomena; but useful mapped representations and quantitative approximations can be made.

The materials or information used to determine patterns of one or a combination of these environmental resources also can have a bearing on the "relative accuracy" or usefulness of the resultant regions. Taking another example from military intelligence, military geographers who define potential areas for a particular type of operation use every piece of useful source material

available, but carefully screen each to interpret its usefulness in combination with other sources. Likewise, domestic mapped information used to determine spatial patterns of resources must also be evaluated for its accuracy (both in the way each map was complied as well as the reference data used) and for the appropriateness of the classifications employed on the map to the purpose(s) of the map user. When using a combination of maps, it is helpful, but certainly not necessary, to use maps of similar scales. However, even if compiled at the same scale and projection, maps of different characteristics compiled independently of each other commonly reflect different levels of generality.

Even more care must be taken in using remote sensing imagery for depicting regional patterns of environmental resources. Because of seasonal, and multi-year variations in resource quality and quantity, and subsequent variations in their appearance on imagery, extensive ground truth, including background information of the study area, is often required to develop useful and less misleading spatial patterns.

Understanding the nature of regional boundaries is also imperative for effective delineation and use of regional frameworks. Whether boundaries are of a broad multi-purpose region, or of a small region that exhibits unique properties, they cannot be thought of as precise lines on the ground, like roads or political units. Boundaries of regions of environmental resources represent transition zones where the characteristics of one relatively homogeneous area blend with those of another. Although imprecise, some boundaries are recognizable from the ground, whereas others are broader bands of transition (more fuzzy) and can be distinguished only from higher altitudes. Regions are somewhat like newsprint photos, made up of dots of different shades, making the photos indistinguishable at extremely close distances. People riding in an automobile across one of the fuzzier boundaries would probably not recognize when the boundary was crossed. However, if they closed their eyes, say 30 miles before crossing the line, and opened them 30 miles beyond the line, they would notice the difference.

PROBLEMS WITH EXISTING REGIONAL FRAMEWORKS

Our experiences in attempting to provide geographical structure for research, assessment, and monitoring of environmental resources by the U.S. EPA have indicated a lack of appropriate existing regional frameworks as well as a lack of suitable methods for their development. We found that

rather than designing an appropriate framework for a specific purpose, or testing and comparing the usefulness of candidate frameworks, resource managers tend to use "off the shelf" frameworks for purposes other than those for which they were intended. For example, in the United States, one of the most widely used spatial frameworks is based on hydrologic units (basins or topographic drainage areas). Undoubtedly useful for tracking the contributions of base streamflow and surface runoff to total streamflow and constituent loading, hydrologic units are often used inappropriately to make assessments and illustrate patterns of water quality, as well as to summarize ecological data (Gallant et al. 1989). Based on topographic drainage divides, these types of regions correspond poorly, if at all, to patterns of factors that are associated with spatial differences in the quality and quantity of environmental resources.

A number of mapped regions for evaluating environmental resources are based on patterns of single characteristics such as soil, vegetation, land-surface form, or geology. In most cases, the use of these frameworks stems from the belief that the particular characteristic chosen is the most important in reflecting the spatial patterns of the environmental resources of interest. Two of the most commonly used in the United States are Küchler's map of Potential Natural Vegetation (1970) and Fenneman's map of Physiographic Regions (1946). A popular global framework is Udvardy's World Biogeographic Provinces (1975), which is based on climax vegetation types, somewhat similar to Küchler's map. Although useful locally for indicating patterns of certain resources, these types of maps do not recognize the importance of other geographic characteristics. Fenneman's map, for example, is one of the most helpful for illustrating differences in aquatic ecosystem quality in the state of Arkansas, but it does not recognize the strongly contrasting regions--ranging from forests, with clear lakes and streams and nutrient poor soils, to rich cropland, with highly eutrophic lakes and turbid streams--in the state of Minnesota.

Another limitation common among single characteristic frameworks is that they may not recognize environmentally distinct regions because of the criteria chosen by the author to clarify the regions. For example, the Sand Hills region in Nebraska is one of the most homogeneous, unique ecological regions in the United States, and is recognized by most national maps of soils, physiography, land use, and vegetation; however, the area is not represented on Fenneman's map (Omernik 1987). Other regional frameworks, while recognizing the importance of more than one characteristic, are based principally on the patterns of only one characteristic at each hierarchical

level of classification, for example, Bailey's Ecoregions (Bailey 1976; Bailey and Hogg 1986), or have emphasized one more than others, regardless of the hierarchical level, because of a particular interest, for example, the Land Resource Regions and Major Land Resource Areas of the United States (Austin 1972; U.S. Department of Agriculture 1981).

Problems can also result from the use of mechanized or quantitative processes to delineate regions (Gallant et al. 1989). Whether regions of environmental resources should be mapped using strictly quantitative techniques or should incorporate qualitative analyses has and will probably continue to be the subject of much discussion. The obvious advantage of a strictly quantitative scheme is that it can more easily be described, and thus replicated and precise confidence limits determined. The recent development and increased popularity of geographic information systems (GIS) has fueled the expectations of supporters of such schemes. Synoptic, qualitative, approaches, on the other hand, rely on an understanding of the phenomenon (or phenomena) for which regions are being drawn, and cannot be easily programmed, if at all. The disadvantages of quantitative approaches (including GIS map overlay schemes) are that they cannot effectively filter spatial variations in the quality and level of generalization of reference data nor can they account for spatial differences in associations and the relative importance of factors that identify regions. Qualitative judgments that consider all available information are necessary to assess patterns region by region and to best approximate regional boundaries. One might think, therefore, of regional boundaries that are the product of a qualitative approach as being "generally right", and those from a quantitative scheme as subject to being "precisely wrong".

The drawback of a qualitative approach is that two different investigators are not likely to arrive at identical regional boundaries. However, it is not likely that two independent investigators would delineate the same set of boundaries using a quantitative approach, because of the qualitative methods necessarily involved in choosing reference data, statistical techniques, weightings, and classification techniques (Gallant et al. 1989). On the other hand, we do not wish to downplay the importance of statistical techniques in regionalization. Such techniques are critical to the testing and verification of any regional framwork. Moreover, as decisions in the game of chess have, after much effort, been made into an expert system, similar attempts will inevitably be made of decision trees for qualitative regionalization approaches that deal with a seemingly infinite number of considerations. This should not be discouraged. It is important to explain the way in which qualitative

judgments must be made in order to allow others to replicate the process as closely as possible, as well as to provide a better understanding of the rationale. Efforts to systematize qualitative regionalization approaches should broaden this understanding.

ALTERNATIVE APPROACHES FOR DEFINING REGIONS

A major focus of the work carried out at the U.S. EPA Environmental Research Laboratory in Corvallis, Oregon, has been regional in nature. To complement the site specific work conducted at this and other EPA facilities, considerable effort has been directed to surveying environmental problems, assessing the spatial extent and trends of environmental resources, clarifying the regional representativeness of site specific research results, and providing spatial frameworks for more effective research and management of environmental resources. Past, existing, and emerging projects include the National Eutrophication Survey (NES) (Gakstatter et al. 1976), the National Surface Water Survey (NSWS) (for effects of atmospheric deposition on acidification of lakes and streams) (Linthurst et al. 1986), and the Environmental Monitoring and Assessment Program (EMAP). Because the objectives of each of these projects and their subprojects have been different, it has been necessary to design different regional frameworks to best meet their needs.

Multi-Purpose Regions

The need for a multi-purpose regional framework to expedite resource assessment and management is universal. Although no two environmental resources are distributed throughout our world in the same fashion, most exhibit patterns in quality and quantity that are somewhat spatially correlated with one another such that regions can be delineated to provide meaning to the analyses and reporting of agencies and scientists tasked with assessing these resources. Ecoregions of the Conterminous United States (Omernik 1987) represents a multi-purpose regional framework designed to meet such a general need. Originally developed to classify surface waters for more effective water quality management, ecoregions are based on combinations of terrestrial characteristics and therefore reflect patterns of terrestrial ecosystems as well. Prior evaluation of existing frameworks, including Bailey's Ecoregions (1976) and Land Resource Regions and Major Land Resource Areas

(U.S. Department of Agriculture 1981), revealed inadequacies and the need for delineating a new framework for water resource management (Omernik 1987; Gallant et al. 1989).

Our approach for defining ecoregions was based on the hypothesis that ecosystems and their components display regional patterns that are reflected in a combination of causal and integrating factors (Omernik 1987). These factors include climate, mineral availability (soils and geology), vegetation, and land use. The relative importance of each of these factors in giving ecoregions their identity varies from place to place at all hierarchical levels of regional definition. A variety of maps thus was used to delineate the ecoregions; those most helpful were land use, landsurface form, potential natural vegetation, and soils.

Since completion of the original ecoregion map, smaller scale, more general regions have been delineated (Omernik and Gallant 1989), as well as larger scale, more detailed subregions of specific areas (Gallant et al. 1989) (Figure 1). The latter were compiled using generally the same methods that were used to develop the original ecoregions. The former represent aggregations of the original ecoregions, grouped according to patterns in resource quality and quantity, as well as natural and human-related factors affecting variations in quality.

The concept of ecoregions of the conterminous United States has been tested and applied in a number of states to (1) assess existing and attainable surface water quality, (2) compare ecological similarities and differences, (3) establish meaningful and reasonable chemical, physical, and biological criteria and goals, (4) determine the number and location of monitoring and demonstration sites, (5) extrapolate results from site specific studies, (6) identify areas that should receive additional resource protection, and (7) predict the effects of management practices on resource quality (Gallant et al. 1989). These tests and applications are documented in Heiskary et al. 1987; Heiskary and Walker 1988; Heiskary 1989; Hughes et al. 1987; Hughes and Larsen 1988; Larsen et al. 1986; Larsen et al. 1988; Rohm et al. 1987; Whittier et al. 1987; and Whittier et al. 1988.

Single Purpose Regions

Many of the environmental assessments that we face involve specific problems and issues, such as the effects of atmospheric deposition on surface water acidification, lake eutrophication, the fate of endangered species, and the effects of global climate change on specific crop or vegetation

types. An ecoregions framework may be helpful in making assessments of these problems, but it will not be as effective as a framework designed specifically for the subject of interest. Although the spatial variations in the existing quality of all environmental resources are related to the combination of geographic factors used to define ecoregions and therefore, the framework reflects the general pattern of all types of resources, a specific problem can often be more precisely regionalized by analyzing the patterns of a single parameter. For example, to identify patterns of lakes and streams in the United States that are potentially sensitive to acidification from atmospheric deposition, maps of total alkalinity of surface waters were prepared (Omernik and Powers 1983; Omernik and Kinney 1985; Omernik and Griffith 1986a; Omernik and Griffith 1986b). These maps were based on patterns of representative data on total alkalinity in lakes and streams and apparent spatial associations between these patterns and mapped information on landscape characteristics such as land use, surficial and bedrock geology, existing and potential vegetation, and physiography. These maps provided a mechanism and rationale for focusing research and survey activities in areas most likely to contain sensitive surface waters.

Another example of single purpose regions is the map of summer total phosphorus in lakes in the upper midwest portion of the Unites States (Omernik et al. 1988). This map depicts regions of homogeneity in phosphorus concentrations in lakes, or similarities in the mosaic of values, as compared with adjacent areas. The regions were delineated to identify patterns in lake trophic state, provide a framework for calibrating mathematical predictive models, and permit more accurate evaluations of the potential success of lake restoration efforts. As alkalinity is probably the best indicator of surface water sensitivity to acidification, phosphorus is generally accepted to be the best measure of lake trophic state. Like the alkalinity maps, the phosphorus map was compiled from analysis of spatial patterns of phosphorus values, as well as patterns in factors such as surficial and bedrock geology, surface configuration, and vegetation, believed to be associated with regional differences in lake trophic state. However, patterns of phosphorus in lakes are far more complex than those of alkalinity, and many of the mapped regions contain a relatively wide range of values. The range in each region (illustrated on the map by a histogram) is different, however, as are the lake and watershed characteristics likely to cause differences in lake quality. These "natural" regions provide a more logical management and assessment framework than political divisions or hydrologic basins.

SUMMARY

Considerable time and effort is being directed toward "what" and "how" global environmental resources should be monitored in order to most effectively support future assessments. Of equal importance is "where" these measurements are taken. We believe that the development of spatial frameworks such as we have described is critical to the design of global monitoring systems and subsequent extrapolation of data from these networks as well as from existing sources. Multi-purpose ecoregions as well as single-purpose frameworks are necessary. Probably most important would be insuring consistency in the development of these regions from one country to another, although this would be an extremely difficult task to accomplish, given the numerous practical constraints.

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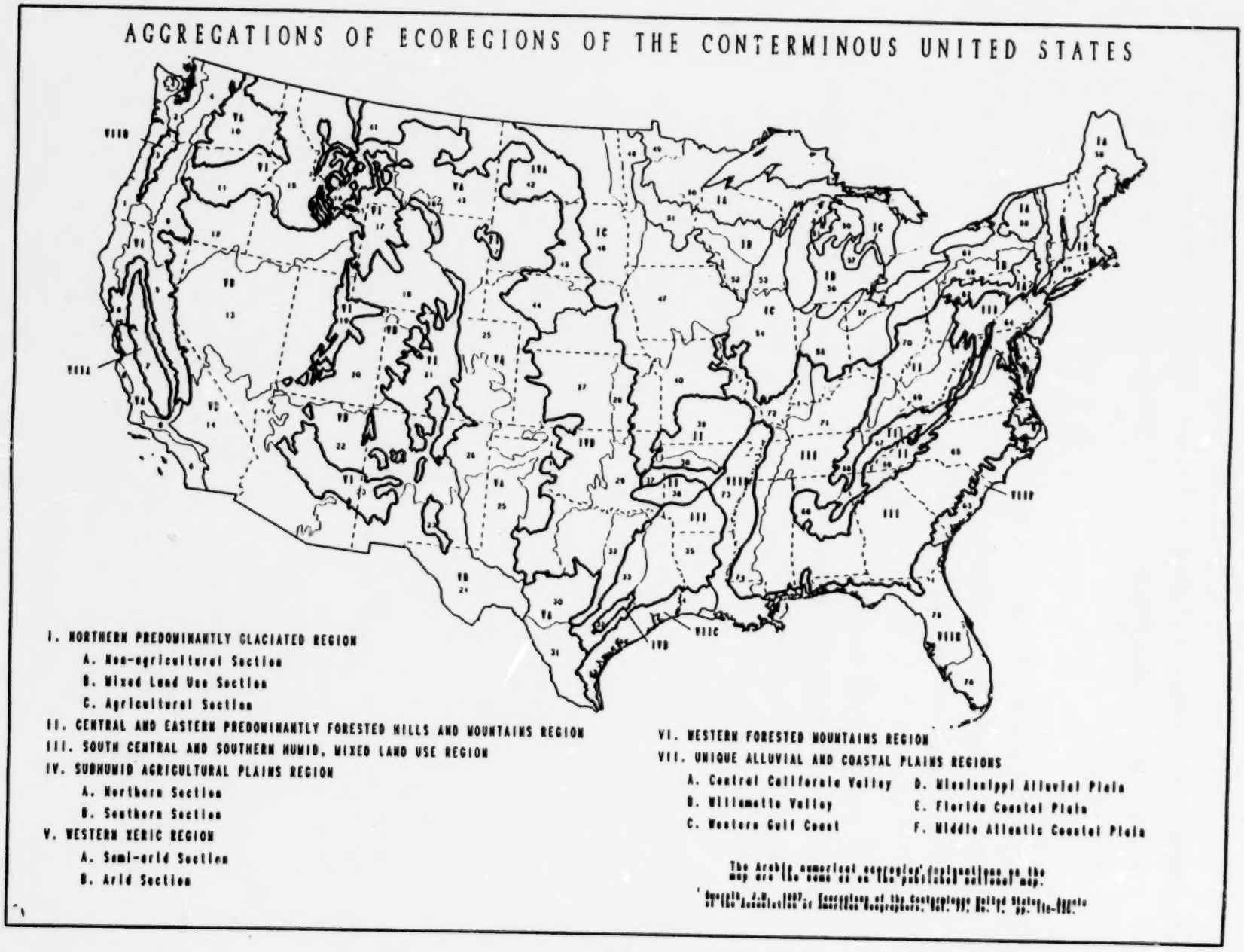
AGGREGATIONS OF ECOREGIONS OF THE CONTERMINOUS UNITED STATES
I. NORTHERN PREDOMINANTLY GLACIATED REGION
A. Non-agricultural Section
B. Mixed Land Use Section
C. Agricultural Section
II. CENTRAL AND EASTERN PREDOMINANTLY FORESTED HILLS AND MOUNTAINS REGION
III. SOUTH CENTRAL AND SOUTHERN HUMID, MIXED LAND USE REGION
IV. SUBHUMID AGRICULTURAL PLAINS REGION
A. Northern Section
B. Southern Section
V. WESTERN XERIC REGION
A. Semi-arid Section
B. Arid Section
VI. WESTERN FORESTED MOUNTAINS REGION
VII. UNIQUE ALLUVIAL AND COASTAL PLAINS REGIONS
A. Central California Valley
B. Willamette Valley
C. Western Gulf Coast
D. Mississippi Alluvial Plain
E. Florida Coastal Plain
F. Middle Atlantic Coastal Plain

Figure 1.